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CONTROL OF EVAPORATION LOSSES

MEMORANDUM

OF THE

CHAIRMAN

TO MEMBERS OF THE

SENATE COMMITTEE ON INTERIOR AND INSULAR AFFAIRS

TOGETHER WITH

A STAFF STUDY

APRIL 14, 1958

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MEMORANDUM OF TRANSMITTAL

UNITED STATES SENATE,
COMMITTEE ON INTERIOR AND INSULAR AFFAIRS,
April 14, 1958.

To Members of the Committee on Interior and Insular Affairs:

The attached interim report summarizes existing information on methods of evaporation control, a subject of interest and importance to this committee.

Concern is general throughout the Nation over the adequacy of water supplies, and this is most acute in the Western States where present use of water approaches the total dependable supply. Increased use of water is, however, essential for the growth of western population and economy. More water is needed for use by agriculture, by municipalities, and by industry.

This report shows that evaporation control can increase the available water supply in substantial amounts.

The study grew out of a suggestion made by our distinguished colleague, Hon. Carl Hayden, chairman of the Committee on Appropriations. Senator Hayden's initial suggestion was that this committee ascertain whether there are opportunities to reduce losses from the water supply of the Lower Basin of the Colorado River. While recognizing that water-supply problems of that area are especially acute, it seemed to me that, to considerable degree, the same problems affect every western river system. With Senator Hayden's concurrence, I therefore directed Mr. E. D. Eaton, consultant on the committee's professional staff, to present information that may apply throughout the West. Copies of my correspondence with Senator Hayden are attached.

As requested, Mr. Eaton's report is brief and nontechnical. In this form, it will be most useful to members of the committee and to other Senators. Subsequent reports will deal with other aspects of the conservation of water supplies, including particularly main channel transit losses.

Evaporation is an enormously expensive waste, and the need to curb it is urgent. A vigorous program is needed to utilize and coordinate the technical resources of the Federal agencies, State colleges and experiment stations, and private research institutions. It should also enlist State water agencies, water-user organizations, and others concerned in conservation of water supplies. The work should focus on practical methods for large reservoirs and also for stock-water ponds and municipal systems.

I will ascertain from the Secretary of the Interior and others what intensification of current activities will be productive. I will keep you advised of progress.

(Signed) JAMES E. MURRAY,
Chairman, Committee on Interior and Insular Affairs.

AUGUST 19, 1957.

Hon. JAMES E. MURRAY,
Chairman, Senate Committee on Interior and Insular Affairs,
Senate Office Building, Washington, D. C.

DEAR SENATOR MURRAY: I know you are fully aware of the ever-present pressure on the States of the Lower Basin of the Colorado River to make the greatest use of the limited available water. Development of the area is so closely related to water that we are constantly pushing against our water supply limits. Because of the critical water situation every avenue should be explored which would bring about the greatest utilization of the available water.

There appear to be, I am informed, impressive possibilities for increasing permissible beneficial use by the reduction of nonbeneficial losses. My attention has been called particularly to main stream reservoir evaporation and main stream transit losses. These losses in the Lower Basin, it appears, may average more than 1½ million acre-feet per year. I understand that recent research by a number of Government and private organizations gives promise of practical means for reducing these losses. Although it would be premature to speculate as to how much water may be salvaged by the methods now being investigated, practical possibilities for savings of any magnitude command our immediate attention.

For this reason I hope that you will be willing to have a member of the Interior Committee staff prepare a report on this subject.

I believe there are quite a number of Federal agencies and private organizations in this country and abroad which may have a contribution to make to such a study. Undoubtedly, State agencies could also contribute to the study.

It occurs to me that your committee staff is the most suitable one to bring together the various technical people and in that way to develop a summary of existing information. Such a summary would be a basis to determine whether legislation is needed for further research or remedial programs.

If this proposal has your approval I will be glad to consult further with you or your assigned staff member and to outline further the suggestions that I have in mind.

Needless to say, this proposed study is in no way related to the litigation regarding Colorado River water rights. In fact, in my judgment, the study and the possibilities for water salvage are equally valuable to all the Lower Basin States regardless of what may be the outcome of the litigation.

Yours very sincerely,

CARL HAYDEN.

AUGUST 23, 1957.

Hon. CARL HAYDEN,
Chairman, Senate Committee on Appropriations,
United States Senate, Washington, D. C.

DEAR SENATOR HAYDEN. I am pleased to adopt your suggestion of a study of methods of conserving water by reducing nonbeneficial losses. In fact, I have acted on it already by requesting Mr. E. D. Eaton, of my professional staff, to undertake the assignment.

Preliminary information is in accord with your judgment that impressive possibilities exist in this field. As you point out, it is too early to speculate as to how much water may be salvaged by reduction of reservoir evaporation and main-channel losses. I am, however, in complete accord that practical possibilities for water savings of any magnitude are so important to the Lower Colorado River Basin that they command our immediate attention. This is equally true, I believe, for many other areas of the country.

The study by the Interior and Insular Affairs Committee is a suitable means for evaluating the existing information and current activities in this field. Significant work is now being carried on by a number of research and industrial organizations and Government agencies. Mr. Eaton will consult with their technical staffs, and he will secure reports on the foreign developments. His report will be an impartial and objective evaluation of progress to date and of the major problems ahead.

Mr. Eaton will devote whatever time is needed for this assignment until the beginning of the next session. By that time, he expects to have an initial report that can be the basis for determining whether legislation or other congressional action is needed. In the meantime, both Mr. Eaton and I count on your offer to consult further with him. This will be valuable especially in guiding the work to significant practical application. At your convenience, Mr. Eaton will discuss with you the plan of work that he will follow.

With kind regards.

Sincerely yours,

(Signed) JAMES E. MURRAY,
Chairman.

CONTROL OF EVAPORATION LOSSES

INTERIM REPORT

BY

E. D. EATON, CONSULTANT

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MEMORANDUM OF TRANSMITTAL

UNITED STATES SENATE,
COMMITTEE ON INTERIOR AND INSULAR AFFAIRS,
March 31, 1958.

Memorandum to Hon. James E. Murray, chairman, Committee on Interior and Insular Affairs.

The attached interim report on control of evaporation losses, pursuant to your instructions, is a brief and nontechnical summary of information on evaporation losses from water supplies and practical control methods. Because of the tight water supply situation in the Western States, major attention is given to those regions.

This interim report summarizes current activities in this country and abroad. It is based on technical publications and personal consultations with technical staffs of the organizations engaged in this work. The volume of the technical data and detailed reports precludes their reproduction here; they are available at the committee office.

Acknowledgment is made of the helpful cooperation received from personnel of the Bureau of Reclamation, especially Messrs. Walter H. Price and Walter U. Garstka of the Division of Engineering Laboratories. The Geological Survey cooperated in supplying information, and a special study was made by Mr. J. S. Meyers of the Denver field office. The Director and staff of the Robert A. Taft Sanitary Engineering Center of the Public Health Service have been most helpful on questions of toxicity and biological effects of retardant materials.

The State agricultural colleges and experiment stations of Texas, Oklahoma, and Colorado provided information on special aspects of evaporation-control problems. Dr. William C. Ackermann, chief of the Illinois State Water Survey, supplied data on control of evaporation in humid areas.

Nongovernment institutions have an important place in current evaporation-control activities. Particularly significant is the research sponsored and financed by a group of Texas water districts, municipalities, and industries organized as the Southwest Cooperative Project for Control of Evaporation From Reservoirs. Technical research for this group is performed by the Southwest Research Institute. Dr. Harold Vagtborg, president of SRI, and members of the SRI staff furnished full information on their work.

A number of chemical companies have furnished data on supplies, costs, and properties of retardant materials.

The Commonwealth Scientific and Industrial Research Organization initiated use of hexadecanol for reservoir evaporation control, and it continues as one of the leaders in this field; its technical papers and popular information bulletins are a principal source of data. Mr. J. E. Cummins, Scientific Counselor of the Australian Scientific Liaison Office in Washington has been most helpful in securing reports of the work of CSIRO.

(Signed) E. D. EATON, *Consultant.*

I. SUMMARY

1. Evaporation from water surfaces is a major cause of water loss in the United States. This loss is greater than the amount of water that is withdrawn for cities and towns. The effect on water supplies is significant even in the humid areas.

2. In the 11 Western States, evaporation from water surfaces averages 11.5 million acre-feet a year. In most western river systems, this loss of water before it reaches the locations of use is one-third as much as the consumption by irrigated crops. In many western areas, evaporation from water surfaces is a critical factor in balancing water supplies and water needs. In the Southwest where the water supply situation is especially acute, evaporation losses are highest in relation to the supplies available.

3. Reservoirs are essential for the conservation and control of western water resources but they also are a major source of evaporation losses. In the Colorado River system, for example, water lost by evaporation from existing reservoirs averages about one-fifth as much as the consumption by irrigated crops, and evaporation from the storage units now under construction will equal more than one-third of the replacement storage that they will provide.

4. Evaporation from small storages, especially stockwater tanks, seriously affects conservative use of land resources in many areas, and it often is an obstacle to efficient livestock operations. The amount of water evaporated from stock tanks often greatly exceeds the amount used.

5. Reduction of losses is accomplished mainly by storing water at maximum average depths, and also by such other methods as phreatophyte control and use of underground reservoirs. Such water-conservation measures undoubtedly will be used increasingly as water supplies become tighter, but physical and economic conditions limit their application. Large quantities of water will have to be stored at relatively shallow depths and, up to the present, this has meant that high evaporation losses have been unavoidable.

6. New methods for chemical protection of water surfaces now give promise of effective evaporation control. In field-scale tests, hexadecanol reduces losses generally in the order of 20 to 30 percent. This method, while still in the stage of test and development, appears to be susceptible of practical application at costs within economic limits.

7. Use of hexadecanol films for evaporation control is not a hazard to health according to the Public Health Service. Other investigations report no significant effects on domestic animals, wildlife, fish, or aquatic biological and stream sanitation conditions.

8. CSIRO, the Australian Government research agency, recommends hexadecanol control of evaporation from small storages such as stock tanks. It estimates that in arid parts of Australia this method will save about one-fourth of the evaporation loss. The cost there per acre-foot of water saved is estimated as between $12 and $25 per acre-foot of water saved.

9. For stock tanks and small storages, technical workers consider that it would be practical in this country to use hexadecanol methods similar to the Australian method. Data are not available for tests to estimate costs here. Extensive demonstration-type tests could provide this information and at the same time work out practical adaptations and improvements.

10. Hexadecanol control of evaporation from reservoirs is not yet sufficiently advanced to warrant recommendations as to methods or costs. Several organizations in this country and abroad are working on development of practical methods, and successful results are reported from Australia.

II. EVAPORATION FROM WATER SURFACES

NATIONAL SIGNIFICANCE

Evaporation takes a large share of all water supplies even before they arrive at the locations where they are used. Water supplies reach the use areas through systems of natural and manmade storage basins and channels, and along this passage evaporation takes a heavy toll. This lost water would otherwise be available for human consumption, for municipalities and industries, and for agriculture.

Because evaporation is gradual, often it escapes notice; yet over a year's time it takes an important fraction of the supply. For example, the water lost by evaporation throughout the United States exceeds the amount taken for use in cities and towns (21).[1]

Even in the humid portions of the country, evaporation loss is significant although annual precipitation tends to mask it. As a result of this, evaporation loss ordinarily is not recognized except during rainless periods such as occurred during the recent drought in the Northeast. Evaporation loss, moreover, may be obscured by large withdrawals for beneficial uses. It is significant, however, because it is a complete loss, whereas most of the water withdrawn for beneficial uses returns to the stream and is available for reuse. For example, over 90 percent of the water withdrawn for cities, towns, and industries returns to streams and aquifers (17), but in contrast, the entire amount of evaporation is lost from the usable supply.

With respect to even the humid Northeast, it has been stated (15) that control of evaporation from water supply reservoirs would be equivalent to about a 10-percent increase in the catchment areas. The significance of evaporation in humid areas is also evidenced in the studies of the Illinois State Water Survey. In this connection, Roberts states:

> Normal evaporation exceeds 3 feet in reservoirs in the southern half of the State (Illinois) where surface waters provide most municipal supplies. Assuming full reservoirs, if evaporation could be reduced by one-third, it would be equivalent to a 17-percent increase in Illinois reservoir storage capacity (26).

The lakes, reservoirs, rivers, and canals that form the water-supply systems all expose water surfaces to evaporation. In the United States, there are about 1,300 lakes and reservoirs with capacities of 5,000 acre-feet or more, and their combined water surface is in excess of 11 million acres; in addition, more than 1½ million farm ponds and stock tanks have an average surface area of 1 acre each (21). Evaporation from these impoundments has been estimated to be more than 20 million acre-feet per year (10).

The water surface exposed to evaporation throughout the United States has increased substantially during recent years, and this trend will continue. Between 1947 and 1954, there was a 71 percent increase in reservoir capacity (29). It has been estimated (38) that, on the

[1] Numbers in parentheses refer to the correspondingly numbered source listed on pp. 25 and 26.

basis of 1980 water supply requirements, reservoir capacities will almost double, and during the next 25 years, 225 million acre-feet of reservoir capacity will be added to the 278 million acre-feet of capacity in 1955. Further increase of both large and small impoundments will also result from continuing programs of flood-control and watershed protection. Although the storage capacities can, to some extent, be utilized for more than one function, there will be a comparable enlargement of the water surface exposed to evaporation.

III. EVAPORATION IN THE WESTERN STATES

EXTENT AND SIGNIFICANCE

In the Western States, losses due to evaporation from water surfaces average 11.5 million acre-feet a year. In most of the West, between 4 acre-feet and 8 acre-feet are lost every year from each acre of water surface. On a per acre basis, this is much more than consumptive use of irrigated crops.

In the Great Basin and the Colorado River regions, where the needs for water exceed the amounts available, evaporation takes almost one-sixth of the entire supply—equivalent to more than one-third of the total amount of water consumptively used by irrigated crops.

In many areas of the West, water-supply limitations retard needed developments and curtail economic and population growth. Such limitation of agricultural development has long been recognized. Now, there is concern also that inadequate amounts of water of acceptable quality may be a deterrent to needed industrial enterprises and even to urban expansion. In the Northern Great Plains States this situation is so acute that in some localities consideration is being given to treatment of brackish ground water in order to make it suitable for community water supplies (39). On the Pacific coast, the urgency is so great that water-supply projects are being planned with the anticipation that their construction costs will finally total several billion dollars. Representatives of these areas contemplate that municipal and industrial water costs up to $100 per acre-foot may be in prospect (39). An example of the economic effect of evaporation from a water supply system is a calculation of the loss from Lake Hefner, the supply reservoir for Oklahoma City. This shows that the average loss due to evaporation is in the order of $660,000 per year (24).

Areas troubled by inferior quality of water are especially damaged by evaporation because it aggravates these problems. Evaporation removes pure water—it is, in effect, distillation that removes pure water and leaves behind the salts. This significantly intensifies the quality problems of water that is stored in stock ponds and municipal water supply systems in the Great Plains (15).

In some areas, the tight water supply situation generates costly litigation, yet in these same areas water lost by reservoir evaporation generally exceeds the amount of water that is in contest. For example, evaporation from Lake Mead exceeds 700,000 acre-feet annually—in the water year 1952–53 it was 875,000 acre-feet (36). Similarly, net annual evaporation from the storage units now under construction in the upper Colorado River Basin is expected to average 691,000 acre-feet, or more than one-third of the replacement storage that they will provide (4).

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The relationships of evaporation losses with water supply and beneficial uses in five major western basins are shown in table I.

TABLE I.—*Surface water, 5 western basins, supplies, uses, and losses*

[Thousands of acre-feet per year]

Basin	Water supply [1]	Uses					Conveyance losses [1]	Evaporation from water surfaces [2]
		Public supplies [1]	Rural [1]	Self-supplied industrial (nonsaline) [1]	Irrigation deliveries to farms [1]	Total (exclusive of waterpower)		
Colorado River	14,570	60	10	130	11,000	11,200	2,500	2,267
Great Basin	11,200	115	20	125	8,300	8,560	2,900	1,870
Pacific Northwest	178,175	650	50	1,190	17,000	18,900	10,000	3,863
South Pacific	71,720	830	20	680	8,400	9,930	2,700	1,384
Missouri River	58,270	530	155	3,835	11,000	15,520	7,100	1,751

[1] Based on data adapted from U. S. Geological Survey Circular 398, 1957.
[2] Data from special study by U. S. Geological Survey, December, 1957. See also table II.

NOTE.—Except for about 570,000 acre-feet diverted into the South Pacific region for public supplies, the basic data do not identify transregion diversions.

Losses from reservoirs

High evaporation loss in relation to usable yield is characteristic of western river systems. This is the result of the climate and the character of the streamflow. The great seasonal variations that are the common pattern of runoff in the West result in large water surface exposure. This is because, through much of these watercourses, spring and summer floods spread over wide valley areas, and low flows meander.

Storage reservoirs are a principal means of improving streamflow regimen so as to increase usable water yield. Reservoirs, however, expose wide surfaces to evaporation, and thus they are a major source of water loss. This is true even though reservoirs may lessen natural evaporation by confining floods in deep pools instead of their being spread over wide flood plains. However, a significant part of most reservoir capacity is relatively shallow, and this is true expecially with respect to carryover storage reservoirs. This, together with the extended periods of holdover, increases the evaporation losses of river systems. The net result of reservoir operation is, of course, advantageous in conserving floods that would otherwise be unusable. The high proportion of evaporation loss from water in storage in relation to other sources of evaporation is, however, shown by the Geological Survey data summarized in table II.

TABLE II.—*Evaporation from water surfaces in the 11 Western States, by major basins (preliminary)*

Basin [1]	Average annual evaporation in acre-feet from—					
	Lakes and reservoirs, WSP 1360-A	Other lakes over 500 acres	Principal streams and canals	Small ponds and reservoirs	Small streams	Totals
Upper Mississippi River and Hudson Bay	3,000	0	0	0	0	3,000
Missouri River	1,052,000	249,000	261,000	150,000	39,000	1,751,000
Lower Mississippi River	100,000	6,000	7,000	34,000	10,000	157,000
Western Gulf of Mexico	158,000	1,000	35,000	38,000	16,000	248,000
Colorado River:						
Upper basin	66,000	17,000	245,000	78,000	31,000	437,000
Lower basin	1,199,000	32,000	473,000	81,000	45,000	1,830,000
Total	1,265,000	49,000	718,000	159,000	76,000	2,267,000
Great Basin	1,103,000	645,000	22,000	74,000	26,000	1,870,000
South Pacific	976,000	72,000	155,000	120,000	61,000	1,384,000
Pacific Northwest	1,808,000	368,000	1,382,000	173,000	132,000	3,863,000
Total for 11 States	6,465,000	1,390,000	2,580,000	748,000	360,000	11,543,000

[1] Data in this table are for only the portion of each river basin that lies within the 11 Western States.

Prepared by J. S. Meyers, U. S. Geological Survey, Dec. 27, 1957.

Losses from stock ponds

In the Western States, evaporation from small impoundments is important because of its effect on land use. This is true particularly with respect to livestock watering places—stock tanks and ponds. Conservative and efficient use of many millions of acres of range land depends on whether the stock tanks have water in them at the right season. A large part of the range livestock water is provided by natural or constructed reservoirs that impound the runoff of small drainages. Generally, because of topography, these tanks are small and shallow, and this, of course, maximizes evaporation loss. Because of the seasonal and uncertain character of runoff in much of the rangeland area, carryover storage from good runoff years would greatly aid efficient use of forage, but this is rarely possible because of the high evaporation loss. These two factors—irregular runoff and high evaporation from the tanks—severely handicap efficient forage utilization and economical livestock operations. This important aspect of the evaporation problem is understood to be receiving special attention at the University of Arizona.

A recent discussion of evaporation pointed out that in the Southern Great Plains the 75 inches average annual evaporation rate results in an annual loss of over 1.4 million gallons per acre of water surface. This loss from a stock pond is as much water as would be consumed in a year by about 500 head of range cattle. In another reference, the Oklahoma A. and M. College is reported to have observed that, during a 6-month period, water taken from a farm pond by evaporation was 10 times as much as the amount taken for use (8).

Rates of evaporation in the Western States are shown on figure 1, prepared by the Geological Survey. The rates shown are in terms of the measurements of standard weather station evaporation pans; reservoir losses generally will be about 70 percent of these determinations.

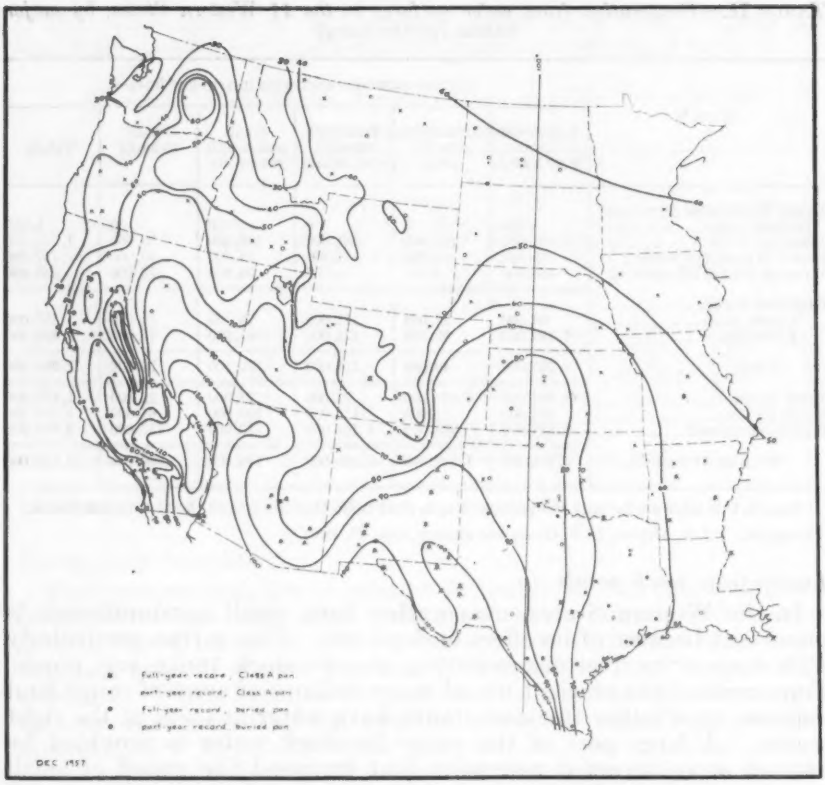

FIGURE 1.—Average Annual Evaporation in Inches, From Weather Bureau Class A Pans. (Preliminary.) Prepared by U. S. Geological Survey, Denver, Colo., December 1957. Reservoir evaporation rates generally are about 70 percent of these pan evaporation rates.

REDUCTION OF EVAPORATION LOSSES

Evaporation losses are held to a minimum by exposing the least possible water surface area. This means that streams and reservoirs are kept deep instead of wide. Familiar examples are stream channel improvement so that the water moves at relatively high velocity through a confined channel instead of being permitted to meander slowly over a wide stream bed. An even more general practice is to use deep, narrow canyons for reservoir sites.

In a recent review of reservoir evaporation control, Mr. S. W. Freese discusses the economic benefits of constructing reservoirs to maximum average depth (14). He refers to a west Texas situation where storage of 40,000 acre-feet in a favorable site avoided the excess evaporation that would have occurred at a less favorable site. Freese states that the water thus saved was worth $164,000 a year. In the same paper, Freese shows comparable benefits from reservoir evaporation control by other methods, including concentrating water into single reservoirs, elimination of shallow areas, elimination of water growths, use of ground-water reservoirs, roofs, floating covers, and windbreaks.

Use of such methods where physically feasible often may be advantageous, and undoubtedly they will be employed increasingly as water supply situations become tighter. There are, for example, many locations requiring phreatophyte control to reduce nonbeneficial consumption of water by plant growths of little economic value. Salt cedar, willows, and cottonwoods not only consume large amounts of water, but also they aggravate channel meandering, thus causing further water loss. Techniques of phreatophyte control are being perfected, and continuing research promises further improvements. A major difficulty, however, is that effective control generally requires repeated treatment with resulting high costs. Possibly, this may be relieved by management techniques that will result in grasses becoming established in place of the phreatophytes.

Another method of evaporation reduction is use of underground storage. Of prime significance in this connection is maintenance of the great natural ground-water reservoirs such as the one underlying the Sacramento Valley of California (25). Many of the underground reservoirs are recharged by percolation from flows in stream channels, and this natural process often is augmented by releases into such channels specifically for the purpose of recharging the ground water. However, the extent to which underground storage can be artificially induced by present methods seems to be limited. Although improvements are being made in recharge techniques, the rate at which water can be introduced into the ground does not permit direct underground storage of large flows. In addition to the physical difficulties, there are also the legal problems of preserving the water so stored from adverse withdrawal. At the present time, it appears that the use of underground storage for surplus surface flows may be suitable mainly for relatively small flows or controlled releases from surface reservoirs, and for situations where underground storage would not be accessible to unauthorized withdrawals.

There are limitations also on the opportunities for management of surface reservoirs to hold storage at maximum depths, although this method is widely and successfully practiced. There are only relatively few deep, narrow reservoir sites at suitable locations, with acceptable geology, and not preempted by railways, highways, and other essential developments. Another limitation of the canyon-type sites is that they do not provide adequate capacity in the canyon section. In practice, therefore, reservoir operations must contemplate that a substantial amount of water will be stored at relatively shallow depths with correspondingly large water surface exposure. Up to the present, this has meant that high evaporation losses have been unavoidable.

New methods for chemical protection of water surfaces, however, now give promise of effective evaporation control. In field tests as well as in the laboratory, monomolecular films of hexadecanol significantly reduce evaporation losses. This method, while still in the stage of test and development, appears to be susceptible of practical application at costs within economic limits. Investigations by a number of governmental and private organizations support the expectation that hexadecanol, along with conventional techniques, can significantly increase the usable water supply by reducing evaporation losses.

IV. THE HEXADECANOL METHOD

Hexadecanol is an industrial chemical used in cosmetics, detergents, and emulsifiers. It is a white, waxy, crystallinelike solid, generally available in flake or powder form. It is relatively tasteless and odorless. Hexadecanol is derived from tallow, sperm oil, or coconut oil. Cetyl alcohol is another name for this material.

Hexadecanol's effectiveness in reducing evaporation has been demonstrated in numerous laboratory and field tests. In laboratory studies up to 65 percent of evaporation losses can be eliminated by a hexadecanol film (35). In experimental field tests, savings are generally in the order of 20 to over 30 percent (22, 24). Australian workers consider that 25-percent reduction of evaporation can be secured by farmers using the hexadecanol method on small ponds (6), and on a large reservoir test there a 37-percent saving is reported (12).

Results of tests vary widely, and large reservoir control operations are dependent on additional research work. Variation in test results may be due in part to differences in the conditions of the tests, or they may be due to differences in the methods used for applying the film; probably also some of the variation in results is due to difficulties in accurate measurement of water losses. As an example of variations in the results of tests associated with seasonal changes, Roberts reports (26) that in a 100,000-gallon tank experiment in Illinois, the 33 percent reduction secured in early September declined to 11 percent reduction by mid-October.

Australian Government authorities recommend the hexadecanol method as a desirable water-saving practice for farmers and stockmen in the water-short areas of that country (6). Preliminary research in this country confirms in general the Australian experience on small ponds, and widespread tests and demonstrations can now round out the experimental work. Such extensive tests would bring about the needed adaptations to actual farm and ranch conditions, and they would also provide reliable data for determining water savings and costs.

Use of hexadecanol on storage reservoirs is dependent on development of suitable techniques for establishing and maintaining the film. The dispensers used on small ponds are effective for only about 1 acre each, and this spacing is, of course, impractical on large reservoirs. There are, furthermore, additional problems on large water surfaces that are not present on small ponds. Wind and wave action, and disturbance by boats, or other moving objects, may be critical in maintaining film coverage of large surfaces. Other problems may also develop from reservoir releases or spills that would remove the film. In order to determine the extent of practical control operations on large reservoirs new methods must be worked out to overcome these and similar factors, and cost data must be secured.

RESEARCH ACTIVITIES

The problems of devising evaporation control methods for large reservoirs, along with improvement of methods for small ponds, currently are being investigated in many countries. An intensive program in Australia is sponsored by the Commonwealth Scientific and Industrial Research Organization, an Australian Government agency. Elsewhere abroad, work is reported by the East African Meteorological Department, and from Brazil, Israel, and Sweden. The International Commission on Irrigation and Drainage, a UNESCO affiliate, sponsors international coordination of evaporation control research.

Most of the work on evaporation control in this country to date has been done by the Bureau of Reclamation and the Southwest Research Institute. The Bureau of Reclamation is concerned primarily in developing practical methods for control of evaporation from the water resources projects for which it has responsibility in the Western States. SRI is a private research organization located in Texas, and in these investigations it does the technical studies for a private association of water districts and industries organized as the Southwest Cooperative Project for Control of Evaporation From Reservoirs. A number of State agencies also are engaged in evaporation control research. These include the State agricultural colleges and experiment stations of Arizona, Colorado, Oklahoma, and Texas, and the Illinois State Water Survey. Several city water departments are cooperating, notably those of Denver and Oklahoma City. The Salt River Valley Water Users Association in Arizona also is initiating a research program cooperatively with the United States Geological Survey. The United States Public Health Service and the Geological Survey are actively cooperating with a number of organizations in their specialized fields.

Current work falls into three main lines of investigation. One line of work is in the nature of basic research in physical chemistry even though it is done largely in the field rather than in the laboratory. These investigations are concerned with how hexadecanol works—how the film is formed, how it heals itself when broken, and similar problems.

A second line of investigations deals with the practical problems of evaporation control methods—that is, how to place the hexadecanol on the water surface, how to maintain the film, in what forms the material may be used advantageously, and what quantities are required under various conditions of climate and surface disturbance. Determinations of costs in terms of water savings is an important part of these studies.

Testing and measuring the effectiveness of the film involves so many novel and difficult problems that the development of these techniques is properly considered a third line of investigations. This includes methods for detecting the presence and extent of hexadecanol films, and it includes also methods for measuring the amount of water that is saved.

BASIC RESEARCH

The use of hexadecanol for evaporation control grew out of laboratory research in fundamental problems of physical chemistry, and, perhaps for this reason, basic problems have been examined somewhat more fully than often is the case for new control operations.

Intensive research on hexadecanol was started about 1925 by Sir Eric Rideal in England, and in this country by Dr. Irving Langmuir and his associates, particularly Dr. Victor K. LaMer, at Columbia University. These investigations, concerned with theoretical problems of physical chemistry, recognized evaporation suppression by hexadecanol as a laboratory phenomenon useful in exploration of these theoretical problems. This research provided an understanding of the nature of the evaporation control process, and it established the maximum evaporation reduction effect that can be secured under laboratory conditions.

In 1953, Mr. W. W. Mansfield, an Australian physical chemist, moved the laboratory problems into the field in order to investigate practical methods for controlling evaporation losses from stored water. Mansfield's work is done under the auspices of the Commonwealth Scientific and Industrial Research Organization. The Bureau of Reclamation began its investigations at about the same time, and shortly afterward investigations were started by the East African Meteorological Department, the Southwest Research Institute, and by the other organizations, all of whose work has been utilized for this report.

How hexadecanol works

The present understanding of the physical chemistry processes of monomolecular films provides a working basis for the improvement of practical evaporation control methods. This understanding has, in the main, been supplied by the research at Columbia University and the work of CSIRO, the Bureau of Reclamation, and other research workers. Continuing research will clarify some of the unresolved questions and this will undoubtedly aid in the design of control methods.

Hexadecanol forms an evaporation-retardant film over the water surface that can be thought of as though it were a roof impervious to escaping water vapor. The process by which this occurs is, however, a far more complicated matter that involves energy relationships of the water molecules and the film molecules (18). The film, only one molecule deep, measures only about six ten-millionths of an inch in thickness. In spite of this extreme thinness, a hexadecanol film that has been suitably formed effectively suppresses the evaporation process that would, in the absence of the film, vaporize the exposed water and dissipate it into the atmosphere. Fortunately, the film that prevents loss of water does not prevent the entrance of rain. Apparently this happens because the raindrops break holes in the film through which they enter, and then the holes heal themselves and close up after the storm.

The extreme thinness of the hexadecanol film seems to be related to its durability. Being thin and flexible, the film undulates with the water surface instead of breaking up, as do the heavy oils that form thick films. Another important property of hexadecanol films is that the molecules of which they are composed stand on end like the bristles of a brush or, according to one description, "as paper matches in a matchbook" (35). The molecules assume this position because one end of the long, spindle-shaped molecule is attracted to water, and the other end is repelled by water.

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Film pressure

The third important property of the hexadecanol film is that, with sufficient hexadecanol available, the individual molecules jam up against each other very tightly. As a result of this tight packing of the bristlelike molecules, water vapor is unable to escape between them. This is the property that makes the films evaporation resistant. It is fortunate that the tight packing together of the hexadecanol molecules, although it prevents the escape of water vapor, is nevertheless porous to the passage of oxygen and carbon dioxide. As a result, hexadecanol films do not interfere with normal gas exchange that is essential to maintenance of aquatic life and sanitation.

Film pressure is the technical term used for the tightness with which the molecules are packed together. The term is defined as the difference between the surface tension of water and the surface tension of water covered with a hexadecanol layer (31). This difference is readily observable by mixing a small quantity of powdered talc with the hexadecanol as it spreads across the untreated water surface. The greater the hexadecanol film pressure, the more rapidly the talc is carried across the surface. Film pressure is measured in dynes per centimeter, which is a standard term of physical chemistry for measurements of force. The more closely the molecules are packed, the higher is the force of the film pressure in dynes per centimeter.

It is important to have the hexadecanol film at a pressure in the order of 40 dynes per centimeter because evaporation reduction is greatest in that range (23), and substantially decreased effectiveness results from lower film pressures. Laboratory observation indicates that marked lowering of the film pressure destroys the ability to restrict evaporation. Maintenance of optimum film pressure is complicated by temperature effects on it, thus indicating that films might have to be fortified with additional material as the temperature changes.

Another finding of basic research that has important application in the design of control methods relates to the manner in which the film is generated. Hexadecanol molecules leave the source of supply one molecule at a time. This separation takes place along the plane of contact between the surface of the water and the hexadecanol mass. As a result, the rate of film formation depends, among other factors, on the size of this contact plane. This means that formation of the film at an adequately rapid rate requires that a large area of hexadecanol material be in contract with the water surface (23). In designing control methods, therefore, hexadecanol is used in a form that will have large surface area in relation to the weight of material used. This is the basis for tests using the material in flake form.

Practical control methods also benefited from theoretical analysis relative to the spacing of film generators. As it is generated from each individual hexadecanol supply source, the film moves outward to cover an ever-increasing water surface area. Because of this radial spread of the film, more molecules are required for each foot of linear extension. The computations of basic research are supported by actual trials in determining that, in order to secure satisfactory film formation, the generators should generally be spaced not farther apart than one generator per acre of water surface (6, 23).

TESTING AND MEASURING TECHNIQUES

Tests for developing improved evaporation control methods have, in general, used two different approaches. One of these approaches, used to considerable degree by the Australian workers among others, is directed to securing sufficient experience to indicate the practical results that can be attained by various control methods. This type of investigations, for example, may assume that the experimental water surface is covered with a film of the desired properties when adequate supplies of hexadecanol are provided at dispensers spaced sufficiently closely. Similarly, in this type of investigations, the amount of water savings accomplished in a test may be considered to be the difference between the water-loss measurements during the test and the evaporation observed elsewhere on untreated areas. This approach has the advantage of rapidly providing a relatively large amount of empirical information with economy of technical manpower and funds. However, it does not provide direct measurements of detailed conditions of each experiment.

Other research workers take a different approach, and they consider that direct measurement of the detailed conditions of the experiments is necessary. The Bureau of Reclamation, for example, has succeeded in devising a technique for measuring film pressure under field conditions of large-scale tests (31). As another example, a technique for measuring the extent of a water surface covered by the film is being developed by the Geological Survey. Direct measurement of evaporation loss from reservoirs or lakes also is difficult. For this purpose, the Bureau of Reclamation and collaborating agencies are able to use Lake Hefner, for which it is possible to compute accurately a water budget of inputs and outputs of water, and thus to determine evaporation from direct measurements (32). The complex preparatory steps have largely been completed, and the Bureau of Reclamation and collaborating agencies expect to make precise tests of hexadecanol films during the 1958 field season.

RESEARCH IN CONTROL METHODS

Current work on development of practical control methods includes investigations of film-forming materials and of techniques for establishing and maintaining the film. The relative cost of various materials and placement techniques is a major factor, and cost determinations in terms of water savings will, therefore, be an essential part of these investigations.

Retardant specifications and dosage

Extensive work, particularly by the Southwest Research Institute (37) and the Bureau of Reclamation (13) accords priority to hexadecanol as the preferred retardant material. Based on comparative tests of more than 125 materials, hexadecanol is now considered the most satisfactory one because of its film-forming properties, ease of handling, nontoxicity, and cost (30).

Because the hexadecanol itself is the main element of treatment cost, dosage requirement is a key factor in comparing different methods and in estimating the economic feasibility of evaporation control in various situations. LaMer has pointed out (18) that a continuous film of hexadecanol over an acre of water surface theoretically requires only

0.01 pounds of material—about one-half cent's worth. This is, of course, only a theoretical calculation, and in actual practice far larger quantities are used. On ponds that do not exceed 2 acres, CSIRO estimates that one-half pound to 1 pound per month is required (6). Bureau of Reclamation trials on the 150-acre Ralston Creek Reservoir used between 0.2 and 0.4 pounds per acre daily (35). However, just how much material is actually needed for various conditions has not yet been satisfactorily determined.

Operating economies should result from current investigations of improved composition and form of the retardant material, use of spreaders, conditioners, and solvents, and by improved techniques of distributing the material. The following examples are typical of the many specific problems encountered, and they indicate the nature of the studies now being made.

The composition of hexadecanol as it is commercially available varies with respect to the other substances that are mixed with cetyl alcohol, particularly as to the proportions of other long-chain alcohols such as octadecanol and dodecanol. These proportions apparently vary according to the supplier, and possibly even in different batches from the same supplier. The effect of these variations on evaporation control is being investigated to determine what standardized composition might be desirable.

Problems have been encountered due to the form of the material as it has been used in floating baskets or rafts for film maintenance. Tests to date have used the commercially available flakes, beads, and pellets of various dimensions. Flakes are fragile and tend to break up and wash away; beads disappear rapidly; pellets have relatively small surface exposure for film generation. Small surface exposure is particularly objectionable in the pressed hexadecanol rods. Currently, promising results are reported from broadcasting directly on the water surface. This technique uses hexadecanol in quite small particles and in mixtures with conditioners to retain particle separation (32). Apparently, hexadecanol can be secured in this form at no significantly increased cost.

A retardant in liquid form appears to have certain advantages. Liquid dodecanol is, for example, the evaporation retardant used in simple equipment designed by SRI for unattended stations. Being a liquid, it is readily dispensed at a predetermined rate through a wick from a reserve material chamber. Biological effects of dodecanol, however, have not yet been determined. It would be advantageous to have a hexadecanol solvent that would be a spreading agent to hasten coverage of the water surface. Benzine, turpentine, ethyl alcohol, and other volatile liquids are hexadecanol solvents, but in this country they are considered unsuitable for use where water might be subject to human use.

Admixture of microbiological inhibitors is being studied as a means of conserving material and also to prevent the slime coatings that interfere with film generation. Microbiological attrition seems to be a significant factor in the high dosage rates required for film maintenance (37).

Control methods for small ponds

Methods for placing and maintaining films take advantage of three properties of hexadecanol: (a) When exposed on a water surface, hexadecanol spreads naturally to form the desired film; (b) when an

adquate supply of hexadecanol is exposed, the film naturally tends to have the high film pressure required for evaporation control; (c) the film naturally tends to be self-sealing, that is, when damaged by wind or the passage of a boat, the film tends to reclose automatically.

The general method for establishing hexadecanol films is by exposing a quantity of the material in small floats with wire-mesh sides through which the outward spread takes place. Various designs have been developed for such floats or rafts depending on local conditions. Descriptions and dimensions of the designs recommended for Australian farm and ranch use are contained in a popular information bulletin published by CSIRO (6). These containers are designed to float about 3 inches above the water surface when carrying the initial load of about 2 pounds of hexadecanol.

Several factors affect spacing of the rafts on small ponds. One basic factor already mentioned is that film spread depends on the ratio of the perimeter of the exposed hexadecanol material to the perimeter of the spreading film front (23). In order to keep within manageable limits the amount of the material that is exposed at each location, rafts are spaced so that there is at least one to approximately each acre of water surface (6). Wind movement is another important factor in location of the rafts. Wind significantly aids hexadecanol spread, and the film is seriously curtailed by contrary wind action. As a result, material may be wasted by being piled up on the lee shore, while the windward side of a pond may be denuded of film. In order to compensate for such wind action, where constancy of wind direction permits, the hexadecanol raft anchorages are clustered to spread the film with the wind.

SRI and CSIRO tests indicate that methods substantially as described are effective and practical on water surfaces of several acres. Further improvements will, no doubt, increase the effectiveness of treatment, particularly by improvement of unattended dispensers, increase of the film durability, and reduction of required dosage. Progress in the current investigations will decrease costs in terms of water saved. Even with present methods, however, costs and water savings as estimated by CSIRO seem to justify hexadecanol evaporation control on small ponds and livestock tanks in water-scarce areas. Data taken from CSIRO (6) are condensed in table III. Unfortunately, no cost and water-saving data are available for tests in the United States.

TABLE III.—*Cost of saving water in small ponds*

Evaporation (feet per year)	Annual saving per surface acre (acre-feet)	Cost of water saved [1]	
		Per 1,000 gallons	Per acre-foot
4	1	$0.075	$24.50
6	1½	.046	15.00
8	2	.037	12.15

[1] CSIRO cost data in Australian currency converted to United States currency at the rate of 1 pound Australian = $2.223 United States.

Source: Data from CSIRO Leaflet No. 15. CSIRO data based on 25 percent reduction of annual evaporation rate from 1-acre pond.

BIOLOGICAL EFFECTS

Hexadecanol used as a film for evaporation control is not toxic to humans or animals drinking the water or swimming in it. Because the film is invisible as well as tasteless and odorless, no perceptible effect on recreational use seems likely (5). The Bureau of Reclamation and the Southwest Research Institute have had the close collaboration of the Public Health Service and State and municipal public health officers in confirming that the hexadecanol method of evaporation control will result in no hazard to public health.

Other biological effects of hexadecanol also seem innocuous. Observations reported to date are that it has no harmful effects on fish or on anglers' ability to catch them. Laboratory tests with several species of fish, aquatic micro-organisms, emergent insects, ducks, and several species of aquatic plants noted adverse effect of the hexadecanol film only with respect to the insects (5). Similarly, field tests indicated no significant adverse effects on lake flora or plankton (5). These tests are continuing both in the field and in the laboratory.

Two effects warrant attention although there is no information to date that suggests seriously adverse consequences. One of these is the biological effects of the increased temperature of the water due to reduction of its natural cooling by evaporation. Observations so far indicate that this temperature rise is not great, and that it is limited to a relatively shallow surface layer. Additional observations will ascertain what will be the effect when there is a high degree of evaporation reduction for an extended period of time. A second effect that will be similarly observed is the increase in certain bacteria which presumably feed on hexadecanol. These are not pathogenic bacteria, and in the tests to date their increase did not produce undesirable taste or smell in the water (5).

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APPENDIX A—STATEMENTS CONCERNING HEXADECANOL RESEARCH ACTIVITIES IN THE UNITED STATES

DEPARTMENT OF THE INTERIOR

Current activities of the Department of the Interior on evaporation are summarized in the letter of November 7, 1957, to the chairman, Committee on Interior and Insular Affairs from Assistant Secretary of the Interior Roger Ernst:

DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
Washington, D. C., November 7, 1957.

Hon. JAMES E. MURRAY,
Chairman, Committee on Interior and Insular Affairs,
United States Senate, Washington, D. C.

DEAR SENATOR MURRAY: This is in response to your letter of October 17, 1957, relating to research in the field of reduction of reservoir evaporation.

Both the Bureau of Reclamation and the Geological Survey are engaged in such research. The Bureau of Reclamation has been engaged in research in the use of hexadecanol, a derivative of whale oil, and synthetic materials of related chemical and physical composition. The studies have demonstrated so far that the physical principles involved in the use of hexadecanol for this purpose are sound and that the substances used are nontoxic. There are no adverse effects on water quality nor on the biology of the water bodies. Although evaporation reduction amounting to 65 percent has been attained on 4-foot diameter class A evaporation pans, we do not know as yet what evaporation savings can be obtained under field operating conditions on large bodies of water.

The Geological Survey is engaged in studies of the physical changes brought about by the introduction of the monomolecular film, especially in the reflectivity of the water surface and the humidity gradient of the air above the surface. The Survey has collaborated with the Southwest Research Institute in carrying out tests on several natural ponds in Texas, where improved dispensing methods have been sought and savings in evaporation losses measured. At present, optical methods of film identification are being explored.

The Bureau of Reclamation laboratory staff has succeeded in maintaining a fully compressed monolayer on Ralston Creek Reservoir, which has an area of about 150 acres, for significant periods of time. Ralston Creek Reservoir is a part of the Denver water supply system on which the Bureau of Reclamation is continuing to study methods of dispensing and detecting the presence of effective monolayers under field conditions. This study is preliminary to large scale tests proposed to be carried out during the coming year on Lake Hefner, a municipal water supply reservoir for Oklahoma City. The Lake Hefner tests will be performed in cooperation with Oklahoma City, the Geological Survey, the United States Public Health Service and the Oklahoma State Department of Health. The Geological Survey will determine the "water budget" for Lake Hefner, including evaporation losses, which is uniquely suited for these tests because the rates of inflow and outflow can be precisely determined and the losses due to seepage and other variations to a water budget can be established.

The Bureau advises me that this method offers promise of successful application to small bodies of water up to about 10 acres in area, with simple dispensing techniques. We are hopeful that further research will prove it successful for application on larger bodies of water where evaporation losses are so great. In view of the general interest in this subject, we have assembled a set of reports and publications prepared by the Bureau of Reclamation and Geological Survey, and are transmitting copies to you and each member of your committee under separate cover.

Mr. E. D. Eaton visited the Reclamation Bureau offices on October 24, where he witnessed a demonstration on the use of hexadecanol and held discussions with Mr. Walter U. Garstka, Chief of the Chemical Engineering Laboratories Branch of the Bureau's Division of Engineering Laboratories in Denver, and obtained direct information from him on the Bureau's program and accomplishments. Additional information regarding the Geological Survey program may be obtained from Mr. C. C. McDonald of the Water Resources Division.

We are pleased to learn of your interest in this matter and we are ready to supply your committee with any further information that it may desire.

Sincerely yours,

ROGER ERNST,
Assistant Secretary of the Interior.

BUREAU OF RECLAMATION

The Bureau of Reclamation program is outlined in the following information furnished by letter of April 14, 1958, from Assistant Commissioner Alfred R. Golzé:

UNITED STATES DEPARTMENT OF THE INTERIOR,
BUREAU OF RECLAMATION,
Washington, D. C., April 14, 1958.

Mr. E. D. EATON,
Consultant, Committee on Interior and Insular Affairs,
United States Senate, Washington, D. C.

DEAR MR. EATON: At the time of your visit to the Denver Federal Center you were given a copy of the memorandum dated November 1, 1957, summarizing, as of that date, the Bureau of Reclamation's programs in relation to the reduction of evaporation through the use of monomolecular layers.

I am informed by the Assistant Commissioner and Chief Engineer that you are preparing a report with appendixes which would summarize the current status of work by various agencies in this country engaged in evaporation-reduction investigations. In order that your report might include the most up-to-date information on our Bureau's programs, I am transmitting a summary dated March 31, 1958, for your use as a replacement for the memorandum of November 1.

Sincerely yours,

(Signed) ALFRED R. GOLZÉ, *Assistant Commissioner.*

APPENDIX ON BUREAU OF RECLAMATION'S INVESTIGATIONS OF RESERVOIR EVAPORATION LOSS REDUCTION

SUMMARY

Attainments of United States Bureau of Reclamation

(*a*) Insofar as can be ascertained, the United States Bureau of Reclamation was the first, in 1952, to propose reservoir evaporation reduction with monomolecular layers, although two others, Mansfield and LaMer, possibly had the conception independently and concurrently.

(*b*) A 64 percent reduction in evaporation loss was first demonstrated by the Bureau of Reclamation using outdoor exposures of class A pans.

(*c*) The Bureau of Reclamation was the first to report on toxicity investigations with regard to fish, ducks, aquatic and emergent insects, aquatic plants, and on gas diffusion studies across the monomolecular layer including oxygen as well as carbon dioxide.

(*d*) The water quality study which the Bureau of Reclamation conducted in collaboration with the city of Oklahoma City, the United States Public Health Service, the Geological Survey, and the Oklahoma State Department of Health, at Kids Lake was the first intensive investigation on a field scale of this complex subject.

(*e*) The laboratory and mathematical analysis of particle size and shape in relation to effectiveness of hexadecanol application is the only work, to our knowledge, performed on this important factor.

(*f*) The Bureau of Reclamation was the first to develop in the high film pressure range and to describe in publications the exact formulation and use of indicator oils for monomolecular film detection and for evaluation of degree of compression. This is the best known method of determining where a film is located on a reservoir surface and its degree of compression which is directly related to its evaporation reducing effectiveness.

(*g*) The Bureau of Reclamation's field studies clearly indicated the impracticability of using floats or stationary containers to dispense a film from a mass of confined particles in relation to large reservoirs.

(*h*) The Bureau of Reclamation physicists applied and maintained a practically fully compressed monomolecular layer on a reservoir of 150 acres in size for periods exceeding several days. As far as is known, this is by far the largest expanse of

water surface which has been successfully covered with a compressed monolayer to date.

(*i*) The Bureau of Reclamation, as far as is known, is the only organization investigating reservoir evaporation reduction with monolayers which has collaborated with the United States Public Health Service on pre- and post-treatment water quality evaluations in connection with the treatment of a municipal water supply reservoir.

(*j*) All of the work performed by the Bureau of Reclamation has been fully and completely described in the laboratory reports and professional society papers which have been available upon request.

Current status of the Bureau of Reclamation program

(*a*) Investigations conducted by the Bureau of Reclamation and others to date indicate that there is no adverse effect on water quality, lake biology, or public health which might result from treatment of reservoir surfaces with hexadecanol monolayers.

(*b*) As Bureau of Reclamation investigations indicated the importance of the shape and size of hexadecanol materials in relation to their effectiveness for evaporation reduction, current work is underway to develop the most practical method of preparing materials to secure optimum evaporation reduction effectiveness.

(*c*) Additional investigations are being conducted to develop field techniques for the measuring of the degree of compression and evaluating extent of cover of effective monolayers on large reservoir surfaces.

(*d*) Based upon work performed to date, and upon information available from other investigators, it is felt that effective treatments could be made on reservoirs up to 10 acres in size provided that film pressures are measured to make certain that attrition losses are being replenished by simple hand applications of powdered hexadecanol materials at high enough rates to maintain a fully compressed monolayer.

(*e*) The Bureau of Reclamation is not in position now (March 1958) to recommend operational applications of a monolayer to large reservoirs. Before recommendations can be made for large reservoir treatment, a hydrologic and economic evaluation on a large reservoir must first be made.

The Bureau of Reclamation's 1958 program

The current program will be pointed toward a full-scale evaporation reduction evaluation to be made at Lake Hefner in the summer of 1958. Two major problems were presented at the conclusion of the Kids Lake study; adequate means of film detection, and evaluation and adequate means of film application and maintenance.

(*a*) Work is underway in evaluating various preparations and forms of hexadecanol in preparation for large-scale tests to be conducted during the summer of 1958.

(*b*) Suitable equipment for dispensing hexadecanol materials is being developed and laboratory tested. Both broadcast and dispenser applications of hexadecanol will most likely be used. Dispensers are being designed so that material will be released only when the wind is blowing past the dispenser and toward the reservoir and at velocities which would not produce white-capped waves.

(*c*) Full-scale testing of film application and maintenance techniques are planned for the 1,000-acre Carter Lake in the spring of 1958, prior to the Lake Hefner test. This would allow for the final technique and equipment modifications in preparation for the Lake Hefner tests.

(*d*) Screening tests are being continued on various additives to hexadecanol in order to attain the compound having the most efficient spreading compression and survival characteristics.

(*e*) Details are being worked out for an interagency collaboration on administrative and technical levels between the Bureau of Reclamation, the city of Oklahoma City, the Geological Survey, the United States Public Health Service, the Oklahoma State Department of Health, and possibly the Weather Bureau, for the performance of full-scale evaluation of a monolayer treatment scheduled for Lake Hefner for the summer of 1958.

(*f*) Before any detailed recommendations for large reservoirs can be considered, the results of the evaluation at Lake Hefner of 1958, must first be analyzed. If significant savings are attained on this 2,500-acre lake, further attention can then be concentrated on dispensers, evaluation techniques, and on studies relating to the most economical methods and schedules of operation whether perennial, seasonal, or pulsed treatments.

(*g*) The Bureau of Reclamation has diligently resisted pressure from the public in general, and certain elements in particular to move to Lake Hefner prematurely. It is extremely important that the Lake Hefner study be executed with utmost preciseness and that it be a true evaluation of the film's ability to reduce evaporation from a reservoir rather than the investigators inability to apply, maintain, and recognize a monomolecular layer treatment. It is clear that an experiment which is badly performed or incompletely controlled could set back the practical use of this technique by many years. Conversely, there is a danger of ill advisedly overaccelerating the program beyond its natural limitations only to the detriment of further developments.

PUBLIC HEALTH SERVICE

The Public Health Service interest in reservoir evaporation research is discussed in the following excerpt from a paper (April 14, 1956) by Mr. H. G. Hanson, Director of the Robert A. Taft Sanitary Engineering Center (see reference No. 15 in the list of references on pp. 25 and 26):

ASPECTS OF INTEREST TO THE PUBLIC HEALTH SERVICE

It is to be expected that a new development such as the one under consideration will set off a chain reaction of experimentation with many compounds, many formulations, many places of application, and several methods of application. As new compounds in new formulations are proposed for application in a variety of ways, it will be necessary to assess the favorable and unfavorable effects of each significant variant.

In parallel with considering the benefits that may result from reservoir evaporation control, it is necessary to evaluate carefully certain possible adverse effects on public health and welfare. Among the specific items of interest to the Service are the following:

(*a*) Physiological effect on humans of the compounds proposed for evaporation control, and their derivatives;
(*b*) Water treatment problems;
(*c*) Effects on fish and other aquatic life;
(*d*) Effects on recreational use;
(*e*) Public understanding.

Physiological effects

Information should be available on toxicity of the substances proposed to be used. It is possible that sufficient toxicological data on many compounds may be obtained by a search of the literature. In other cases such information will need to be supplemented by consultation with such public agencies as the Public Health Service and the Food and Drug Administration, and with various private agencies, particularly industry. When sufficient information is not available, toxicological studies may be required. With reference to one candidate compound, cetyl alcohol, the Food and Drug Administration has indicated that no hazard to man or animals would be expected from its application in the manner and range of concentration proposed for use: the compound, free of significant toxic impurities, would be dispersed in the solid state or in such solvents as ethanol or acetone, in amounts necessary to produce an essentially monomolecular layer.

The effect of the added substance on the taste and odor of the finished water supply also requires consideration. Unacceptable tastes and odors evoke widespread and spirited protests that are most troublesome for the waterworks operator. Even extremely low concentrations of substances or their reaction products may produce objectionable conditions. Most water plant operators are familiar, for example, with the greatly accentuated tastes produced by chlorinating phenol.

Water treatment problems

Applied materials reaching the water treatment plant may impair the normal efficiency of water treatment processes. Emulsifying agents and agents that reduce surface tension interfere with the chemical coagulation process, as do certain components of detergents. Film substances resisting the coagulation process and reaching the sand filters may impair their effectiveness. Although the chlorine demand may have to be considered, it probably will not be significant in most cases. If difficulties such as these occur, either preventive or corrective measures will need to be devised.

Effect on aquatic life

The possible effects of films on fish and other aquatic forms is another matter of interest. Chemical compounds proposed for use may be capable of exerting damaging effects in several ways. A direct toxic effect either acute or chronic in

nature may be produced. If the film constitutes an appreciable barrier to the transfer of oxygen from the atmosphere into the water, or to the escape of carbon dioxide and other gaseous products of aquatic metabolism and organic decomposition, some effect on aquatic ecology would be expected. Theoretically, gas transfer balances should not be affected significantly by the applications thus far proposed. An increase in temperature resulting from a reduction in evaporation could damage fish or organisms providing food for fish directly, or could adversely affect gas transfer balances.

The short-range toxic effect of chemicals on fish life may be rather simply determined by means of bioassay procedure. The Sanitary Engineering Center has for some years been using such a procedure in the determination of the pollutional effect of wastes. Because films that effectively reduce evaporation presumably will be used either continuously or over a prolonged period, the waterworks authority should not ignore possible long-range effects on aquatic life.

Temperature rise following reduction of evaporation has been observed, but not fully quantitated. Few warm water fish can tolerate prolonged temperatures above 96° F. Such levels may be reached in the upper strata of lakes and impoundments during hot weather. Since temperature rises have the further effect of increasing the activity of fish and thereby increasing their oxygen requirements, it would appear desirable to investigate the combined physiological effects of increased temperature and reduced dissolved oxygen content.

Effect on recreational use

The possibility of damage to recreational uses of the impoundment should be considered. Unsightly deposits of materials on the shoreline and clinging of material to the bathers would be expected to produce complaints. In the experiments conducted to date, these effects have not been observed. Interference with aquatic sports, fishing, and wildlife also should be considered.

Public understanding

Waterworks officials know probably better than anyone else the importance of keeping the public informed regarding matters affecting the water supply. The nature and progress of studies and the really worthwhile benefits that would be realized in successful reservoir evaporation control are matters of considerable interest to the public. Keeping the public informed can minimize exaggerated and distorted rumors that could seriously retard the course of the work, and further can be helpful in obtaining the necessary support for the undertaking.

SUMMARY

Physical and chemical characterization and measurement of monomolecular films will demand the application of methods and theoretical considerations not frequently encountered in the analysis of water supply systems. The chemistry of monolayers has been developed and applied experimentally by relatively few investigators and has challenged the skill of the best. While orthodox analytical approaches will have applicability in some phases of the proposed studies of water evaporation suppression, it is certain that in major facets of the work a projection from the ordinary concepts of bench chemistry into the relatively restricted two-dimensional limitations of surface structure will be necessary. Empirical determination of the effectiveness of chemical suppressants will be quite easy, but development of a reasonable theoretical basis for compound selection, dosage control, and efficient application will challenge the most skilled of our scientists.

A broad program of research on the feasibility of conservation by means of reservoir evaporation control should include an evaluation of possible adverse effects. The Robert A. Taft Sanitary Engineering Center of the Public Health Service proposes to contribute to cooperative studies by developing a framework of methods and procedures usable by Public Health and other agencies in the appraisal of public health and other factors related to the use of film-producing chemicals. Certain specific studies are being undertaken immediately in respect to the effects of designated film-producing materials on humans, on aquatic life, and on water-treatment processes. During the course of our investigations, we expect to maintain active liaison with Federal and other governmental agencies and with nongovernmental research organizations engaged in such studies. It will be our purpose to provide such assistance in regard to public health phases of the development as is appropriate to the functions of the Public Health Service.

In conclusion, I would like to emphasize our opinion that the conservation of water by reservoir evaporation control merits careful study by all agencies interested in water resource development.

SOUTHWEST RESEARCH INSTITUTE

The research program of the Southwest Research Institute is described in the following excerpt from a paper delivered October 15, 1956, by Buell W. Beadle, formerly chairman, Department of Chemistry and Chemical Engineering, SRI, and Robert R. Cruse, SRI staff member (see reference No. 3 in the list of references on pp. 25 and 26):

The Research Program

The proposed research program was designed to give information on the following subjects:

1. The present status of development by others.
2. The best compound to be used.
3. The best methods of application.
4. How the films work.
5. The coverage and life of a film.
6. The biological effects.
7. The effect on objects in the water.
8. The effect of physical factors such as water, temperature, rain, dust, freezing, and wave action.
9. The general effectiveness of the treatment.
10. The cost of treatment in terms of acre-feet of water saved.

The first phase of the program consists in the compilation of a complete bibliography on all subjects relative to water evaporation and its control. This includes theory, suitable methods, means of application, techniques for water evaporation measurement, and all obtainable results of work to date.

The second phase concerns the preliminary laboratory work involved in the screening of organic chemical samples (fig. 1) [1] that may be suitable for water evaporation control. As a result of publicity, more than 146 different samples have been submitted by individual companies for testing. Some of the samples were submitted upon request and others were offered voluntarily. They are of a great variety of materials—alkanols, organic acids, amines, amides, ketones, silicones, diols, and similar compounds. Some of the samples are not pure compounds but are mixtures, such as preparations derived from the treatment of oils and fats (tallow), and inert materials like ground plastics, plastic bubbles, ground cork, and plastic air pillows and membranes.

A fundamental study will be made of the physical chemistry of monomolecular films and suitable substances with the objective of correlating molecular structure or physical properties with their effectiveness as water evaporation retardants.

The major part of the biological work will be done by the USPHS. This will include tests for toxicity of the chemical compounds to be used, their effect on marine animal and plant life, their effect on oxygen and carbon dioxide transfer rates between air and water, and similar studies. Under the direction of Bernard B. Berger, work is underway at the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio.

Concurrently with the laboratory screening tests, evaluation of hexadecanol and other materials showing promise in the screening work is being investigated in 10-foot stock tanks (fig. 2).[1] This is the third phase and will evaluate in a preliminary way the performance of the film under field conditions. In addition to providing a further screening of evaporation retardants showing promise in the laboratory, this phase is expected to provide a technique which can be used on similar tanks on ranches and farms after the toxicological effects of the material or materials used have been investigated. Climatic effects, methods of application, life expectancy, and so on, can be explored further during this phase.

In the fourth phase, the work will be performed on a larger scale—in swimming pools, ponds, and reservoirs up to 5 acres in size. Those compounds showing

[1] Illustrations not reproduced here.

the most promise in the second and third phases will be further evaluated. At this stage, the cost and economics of the process can be calculated with some reality. A large part of the work of this phase will be conducted in cooperation with the USGS at Denver, under the direction of G. Earl Harbeck.

As the final step in the program, as now outlined, it is planned to present a schedule of tests and a program for treating large reservoirs (several hundred acres to several square miles). This will be done only after full clearance has been obtained from local, State, and United States Government agencies, such as the local health departments, fish and game commissions, State health department, USPHS, Food and Drug Administration, and others. Assistance will be secured from the United States Bureau of Reclamation and the USGS. Thus, large bodies of water—particularly those used by animals or humans as drinking water sources—will not be used in the testing program until all possibilities of deleterious effects have been eliminated.

Current tests

In the chemistry and chemical engineering laboratories at the institute, the screening tests are near completion. One hundred thirty-six samples had been evaluated as of September 1, 1956. The screening apparatus consists of an insulated, constant-temperature bath containing water kept at about 30° C. Battery jars placed in the trough contain the water under test. Sweep air is dried by passing it over silica gel. It then flows over the water surface at 0.3 miles per hour. Water levels are kept constant automatically by means of inverted, closed-top cylinders (similar to a chicken-watering device). Test dosage has been 1 pound of material per acre. Twelve samples and two control tests make up each test bank.

The fatty alkanols have performed best to date. Although the fatty acids and fatty amides are known to form monofilms—and the former, under most precise laboratory conditions, gave over 99 percent reduction of evaporation—neither type of compound has done well under conditions here. It is felt that the test conditions at the institute give a fair indication of performance to be expected, at least for a short time, in the larger field tests. Tests which have been conducted in the 10-foot stock tanks tend to confirm this.

Four of the best materials produced by the screening program have been evaluated in the 10-foot tanks. Excellent reduction of evaporation has been achieved, but only for a short time—5 to 8 days. Ways to increase the film life are being studied.

The basic evaporation and seepage characteristics of a 4-acre lake located on the Essar ranch about 6 miles from the institute have been determined in cooperation with the USGS at Denver. Two sets of tests have been conducted, one with hexadecanol and one with octadecanol. The technique of application was apparently faulty, as little, if any, evaporation reduction was produced. The work will be continued as rapidly as possible. The USPHS indicates some bacterial attack on hexadecanol. Results are preliminary, however, and investigations are continuing.

ILLINOIS STATE WATER SURVEY

Research by the Illinois State Water Survey is summarized in the October 23, 1957, letter to Mr. E. D. Eaton from Mr. William C. Ackermann, Chief.

STATE OF ILLINOIS,
STATE WATER SURVEY DIVISION,
Urbana, Ill., October 23, 1957.

Mr. E. D. EATON,
Consultant, United States Senate,
Committee on Interior and Insular Affairs,
Washington, D. C.

DEAR MR. EATON: Thank you for your letter of October 16, and your interest in our studies in evaporation control.

Most of our studies have to do with the use of hexadecanol and methods of application.

Our studies started in the early spring of 1956 with two identical small pans filled with water. One had hexadecanol applied to the surface, the other was used as a check.

In June 1956, two 55-gallon drums, with one end of each removed, were buried adjacent to each other. The open ends of the drums extended 2 inches above the ground surface and were filled with water to ground level. The water surface of one was coated with hexadecanol flakes, the other was used as a check. There were days during July and August of 1956 when the containers with the hexadecanol had a water loss of nearly 30 percent less than the containers without the chemical cover.

In August 1956 a 100,000-gallon ground storage reservoir was treated with hexadecanol. In all the 1956 studies benefits from hexadecanol appeared to decline 3 or 4 days after treatment.

Incorporated in our 1957 studies were methods of application to overcome this decline. We used two adjacent ponds having surface areas of about 4 acres each and a 234-acre lake.

Several different grades and sizes of hexadecanol were applied to the pond from feeders anchored near the centerline of the pond. Next, different grades of material were applied to the pond directly from a rowboat. A third method was to apply hexadecanol continuously to the pond as a sort of slurry.

Hexadecanol was applied to the 234-acre lake by the use of two pots secured to the side of a motorboat that cruised the lake. Analysis of this season's data have not been completed.

Next season we plan to continue the study of methods of application of hexadecanol and the use of other chemicals together with the biological attrition of these chemicals.

Very truly yours,

WILLIAM C. ACKERMANN.

Appendix B—Toxicological Opinions

The finding of the Public Health Service relative to toxicological aspects of hexadecanol and dodecanol is stated in the following correspondence:

United States Senate,
Committee on Interior and Insular Affairs,
November 25, 1957.

Assistant Surgeon General Mark D. Hollis,
Chief Sanitary Engineering Officer, Public Health Service,
Department of Health, Education, and Welfare,
Washington, D. C.

Dear General Hollis: In accordance with the recent communication from the Honorable James E. Murray to Secretary Folsom, and his acknowledgment of October 30, I conferred with staff members of the Robert A. Taft Sanitary Engineering Center regarding toxicity of evaporation suppression agents. Mr. Harry Hanson and Mr. Bernard B. Berger were most helpful in providing me with information and publications relative to the study being prepared for this committee.

During our discussion, reference was made to technical opinions of your toxicologist regarding hexadecanol and dodecanol. I will appreciate receiving from you copies of these opinions.

May I express appreciation also for the thorough and thoughtful responses I received from Messrs. Hanson and Berger.

Sincerely yours,

E. D. Eaton, *Consultant.*

Department of Health, Education, and Welfare,
December 18, 1957.

Mr. E. D. Eaton,
Consultant, Committee on Interior and Insular Affairs,
United States Senate, Washington 25, D. C.

Dear Mr. Eaton: This is in reply to your letter of November 25, 1957, in which you request a technical opinion on the toxicological aspects of using hexadecanol and dodecanol as evaporation suppression agents.

It is our opinion that no hazard to the public health will result from the use of hexadecanol in the quantities proposed to produce a monomolecular film on water-supply reservoirs.

Available information on dodecanol is not sufficient to justify a similar opinion, and consequently we believe that until further information becomes available, dodecanol should not be used for suppression of evaporation from water-supply reservoirs.

We appreciate the opportunity to work with the committee on this matter.

Sincerely yours,

M. D. Hollis,
Assistant Surgeon General,
Chief, Division of Sanitary Engineering Services.

Opinion on Toxicity of Hexadecanol Proposed for Use in Evaporation Control

Chief, Toxicologic Services, Occupational Health Field Headquarters, Public Health Service, Cincinnati, Ohio

It is our opinion that no hazard to public health should result from the use of hexadecanol in the amount and manner proposed to produce a monomolecular film on water surfaces in evaporation reduction.

Although there is no report of information known to us on the long-term ingestion studies of hexadecanol, this material in one form or another has been used in a domestic manner for many years without evidence of detrimental effects on the health of individuals. Indirect, but important, evidence indicating safety in the use of the long-chain alcohols is presented in the work of Treon (1) of the Kettering Laboratory. Treon found that the oral toxicity of aliphatic straight-chain alcohols decreased sharply at the C–10 chain-length. This implies that alcohols of longer chain-length, because of lessened solubility and other characteristics, would have still further reduced toxicity. Supporting evidence is contained in the work of Stetten and Schoenheimer (2) who noted that hexadecanol is oxidized to the corresponding fatty acid, palmitic acid. This is a component of normal fat which, of course, is a common foodstuff. Additional supporting evidence is the information provided by A. J. Lehman (3), who cited evidence that amounts of hexadecanol up to 0.1 percent in the diet were completely metabolized (like a fat) and that the Food and Drug Administration saw no objection to application of hexadecanol to produce monomolecular layers, provided the alcohol is pure and the materials applied with it are harmless.

Octadecanol, tetradecanol, and the unsaturated C–18 alcohols, often associated with commercial hexadecanol, are normal metabolites of commonly ingested foodstuffs, and consequently would not be expected to present a health hazard upon ingestion in any reasonable amount.

Accordingly, in view of (*a*) the lack of direct evidence of the hazard to health upon ingestion, (*b*) certain evidence favoring the view of its probable innocuousness, and (*c*) the improbability of ingestion of any but extremely trivial amounts as a result of the method of use, it does not seem reasonable to anticipate that any hazard to health would result from its use for the purpose of producing monomolecular films on water surfaces, and under the conditions proposed for this use, even though exposure were to be for the lifetime of the individual.

It is necessary to add that chemicals used with hexadecanol could conceivably produce a mixture with enhanced toxic properties. Therefore, preparations proposed for use should be independently reviewed for possible toxicity potential.

REFERENCES

(1) Unpublished data. J. F. Treon, the Kettering Laboratory, Cincinnati, Ohio.
(2) DeWitt Stetten, Jr., Rudolf Schoenheimer, The Biological Relations of the Higher Aliphatic Alcohols to Fatty Acids. J. Biol. Chem. 133, pp. 347–57 (1940).
(3) Oral communications from Dr. Arnold J. Lehman, Chief, Division of Pharmacology, Food and Drug Administration.

Opinion on Toxicity of Dodecanol Proposed for Use in Evaporation Control

Chief, Toxicologic Services, Occupational Health Field Headquarters, Public Health Service, Cincinnati, Ohio

Available information is inadequate to justify a favorable opinion on the use of dodecanol for the purpose of producing a monomolecular film on water surfaces in evaporation reduction.

The evaluation of acceptability of dodecanol (lauryl alcohol) as an aid in control of evaporation of water from reservoirs is based on the following information which constitutes all of that available to the above-signed at the present time. Data may be obtained from other sources, such as the Food and Drug Administration, or in certain company files, but it is believed that sufficient information is already available for the development of an opinion.

The unpublished work of Treon (1) on the minimal lethal oral toxicity for animals using single doses of the aliphatic alcohols, including dodecanol, indicated a sharp decrease in toxicity at the C–10 chain-lengths (decanol). One infers from this that the alcohols of longer chain lengths, because of lessened solubility and consequent absorbability, would have still further reduced toxicities. The irritant properties of the alcohols, including dodecanol, are not reduced, however (2).

Lauryl alcohol is a closely related reduction product of a constituent of coconut oil. I have received information (2) that a product of lauryl alcohol, lauryl gallate, has been approved by the Federal Drug Administration for use as an antioxidant in foods. This approval was based on information of the type

described by Allan and DeEds (3) in which long-term feeding experiments of albino rats, involving concentrations of lauryl gallate as high as 0.5 percent in the diet produced no observable adverse effects; higher levels definitely produced toxic effects. A Japanese report (4) involving a toxicity study in rats of a series of fatty alcohols, from C6–C18 including dodecanol, indicated a toxic effect was obtained with dodecanol, but not with hexadecanol, under similar conditions of test. These results are at variance with the above-quoted American experience, and could possibly be attributed to dietary inadequacies in the Japanese study.

On the other hand, the irritant properties of lauryl alcohol are well known. Those of coconut oil are ascribed to its lauryl acid ester component. The irritant property of dodecanol is a plaguing one in the light of current knowledge that irritants may enhance the carcinogenicity of cancerigenic agents.

It is therefore believed that before the use of dodecanol can be approved for the purpose of producing monomolecular films on water surfaces, further toxicological studies data justifying a favorable opinion should be obtained.

REFERENCES

(1) Private communication to above-signed by Dr. Joseph F. Treon, past chief toxicologist, Kettering Laboratories, Cincinnati, Ohio.
(2) Private communication from Dr. John A. Zapp, Jr., Haskell Laboratory, E. I. DuPont de Nemours & Co., Wilmington 98, Del.
(3) Allen, S. C., DeEds, F. The Chronic Toxicity of Lauryl Callate, J. Am. Oil. Chem. Soc. 28, 304, 1951.
(4) Miyazaki, M., Nutritive Value and Toxicity of Saturated Alcohols with 6–18 Carbon Atoms, J. Agr. Chem. Soc., Japan 29, 501, 1955.

Appendix C—Report of an Australian Reservoir Evaporation Field Test

The following quotation from the May 1957 issue of Research (see reference No. 12 in the list of references on pp. 25 and 26) reports a recent Australian field-scale test:

> As we go to press, notification has just been received of the successful completion of a program of tests of the Mansfield process on a large reservoir at Broken Hill. Over the 14 weeks ending April 8, evaporation from the Stephen's Creek Reservoir, Broken Hill's main water supply, has been reduced by 37 percent, it is claimed. More than 200 million gallons of water, equivalent to 6 weeks summer consumption in Broken Hill, are stated to have been saved. From this experiment the estimated cost of the water saved is 1 penny [1] per 1,000 gallons. It is expected that under less favorable conditions the cost of saving water will be greater but will not exceed sixpence per 1,000 gallons. In these tests, it is stated that a satisfactory film of cetylalcohol was maintained for more than 3 months in spite of exceptionally high wind velocities. About 1 foot of evaporation has been saved over an average area of 930 acres. It is suggested that these results indicate the way to apply this process to the largest water storages, although additional research may be required to deal with new difficulties encountered.

[1] Approximately 1 cent United States (1£Australian=240 pennies=US$2.223.).

Appendix D—Note Regarding the Effect of Reservoir Evaporation on Climate

Reservoir evaporation control would not intensify the dryness of arid areas in the West because reservoir evaporation does not materially increase the humidity of the air a short distance away. This is strikingly demonstrated in the Southwest. Large reservoirs on the lower Colorado and Salt Rivers for several decades have annually dissipated hundreds of thousands of acre-feet of water into the air without causing a perceptible change in the surrounding desert vegetation.

It may be initially confusing to reconcile the insignificance of reservoir evaporation in terms of its contribution to atmospheric moisture with its major effect on water-supply requirements. This apparent paradox is clarified by considering that, even in the drier parts of the country, atmospheric moisture represents an enormous amount of water whereas in most of the West the margin between the usable water supply and water requirements is precariously small.

Moisture for precipitation and for atmospheric humidity even in inland and intermountain regions is derived mainly from the ocean surfaces. This moisture, traveling in great air masses, is so enormous in total amount that any contribution from reservoir evaporation is comparatively negligible. For example, the average annual water content of the air above the Western States is in excess of 1¼ billion acre-feet. This is about 100 times as much as the evaporation from water surfaces.

Another factor that discounts any effect of evaporation control on atmospheric humidity is that such control merely defers, rather than diminishes, evaporation. That is, reservoir evaporation control conserves the water for uses at downstream locations, where it then is evaporated substantially as would have occurred at the reservoir. Thus, although reservoir evaporation control will materially increase beneficial use of water, it will not materially reduce the amount of the contribution to atmospheric moisture in a river basin.

The relationships of runoff, water loss, and atmospheric water vapor are indicated by the following data for major river basins, prepared by Mr. A. L. Shands of the Weather Bureau:

TABLE IV.—*Approximate water losses, by river basins* [1]

Region	Area (thousand square miles)	Average precipitation (inches)[2]	Runoff (inches)	Water loss		Atmospheric water vapor content (inches)
				Inches	Million acre-feet	
North Atlantic	59	44	24.0	20	62.9	0.70
Upper Hudson	13	44	22.0	22	15.2	.70
Lower Hudson and coastal area	6	45	21.0	24	7.7	.75
Delaware	12	44	21.0	23	14.7	.75
Chesapeake	57	40	19.0	21	63.8	.75
Eastern Great Lakes and St. Lawrence	47	36	18.0	18	45.1	.70
Western Great Lakes	81	30	11.0	19	82.0	.70
Upper Mississippi	182	30	7.2	23	223.1	.75
Southeast	279	49	16.0	33	490.7	1.10
Tennessee-Cumberland	59	50	21.0	29	91.2	.95
Ohio	145	41	16.0	25	193.2	.85
Missouri-Hudson Bay	580	22	1.9	20	618.3	.65
Lower Mississippi	64	52	16.0	36	122.8	1.15
Arkansas-White-Red	270	31	7.0	24	345.4	.85
Western Gulf	341	27	3.2	24	436.2	.90
Colorado	258	15	1.1	14	192.5	.60
Great Basin	200	13	1.1	12	127.9	.55
Pacific Northwest	257	30	13.0	17	232.9	.60
South Pacific	112	29	12.0	17	101.5	.75

[1] Regions, drainage areas, and runoff from U. S. Geological Survey Circular No. 398.
[2] Estimated by eye from enlarged copy of United States precipitation map published in Crop Bulletin Jan. 10, 1957.

Prepared by A. L. Shands, Weather Bureau, Washington, D. C.

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